Emission Characteristics and Concentrations of Gaseous Pollutants in Environmental Moxa Smoke

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ABSTRACT

The burning of moxa floss in moxibustion constitutes a major anthropogenic source of many gaseous pollutants, which has been associated with many different negative environmental health effects. The aim of the present study is to systemically study the concentration of gaseous pollutants emitted from different types of moxa floss combustion and present key information in abbreviated tabular form to assist in the assessment of air quality in moxibustion clinics and contribute to the safety evaluation of moxibustion. Sampling was divided into pre-combustion, combustion and post-combustion phases. The pollutants determined were carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) produced by burning three types of moxa floss samples. The average post-combustion concentrations for CO, CO_2 and NO_2 in moxibustion clinics were 9.333 ppm, 0.138% and 10.556 μg m^{-3}, respectively. SO_2 was below detectable limit. NO_2 concentration decreased during post-combustion, possibly as a result of reactions from moxa floss combustion. The levels of target gaseous pollutants from 4 g of moxa floss combustion were not produced in quantities that exceeded present international air quality standards and occupational exposure limits. Data from our study is important for the recognition and control of occupational and non-occupational gaseous exposure and for the assessment of air quality in moxibustion clinics by professional authorities.

Keywords: Moxibustion; Gaseous pollutants; Moxa smoke.

INTRODUCTION

Moxibustion is a therapeutic procedure using ignited moxa floss to apply heat to certain points or areas of the body surface for treating disease (World Health Organization, 2007). Smoke from the burning of moxa floss products, or environmental moxa smoke (EMS), has raised the possibility of its association with possible health problems and sensitization due to occupational and non-occupational exposure among practitioners, workers and patients in moxibustion clinics.

It has been recognized that combustion emissions constitute a complex mixture of pollution components and combustion processes are major anthropogenic contributors of many classical air pollutants, for example, carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter (PM), which have been associated with many different negative environmental health effects. There is also mounting evidence from epidemiologic studies regarding the associations between SO_2, NO_2 and CO exposure and increases in cardiopulmonary hospital admissions and mortality, and cardiovascular emergency admissions caused by stroke (NO_2) and myocardial infarction (NO_2 and CO) (Tarlo *et al.*, 2001; Koken *et al.*, 2003; Tsai *et al.*, 2003).

Given the lack of information regarding the concentration of gaseous pollutants in moxa smoke emitted from moxa floss combustion, the present study is an extension of our previous work on the PM_{10} mass concentration and oxidative capacity of moxa smoke. (Huang *et al.*, 2015) The purpose of this study was to systemically study the concentration of gaseous pollutants in EMS released from burning different types of moxa floss. The pollutants determined were carbon

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monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). Our study aims to present key information and data of gaseous pollutants in moxibustion clinics in abbreviated tabular form to provide a basis for the assessment of air quality in moxibustion clinics and contribute to the safety evaluation of moxibustion. We decided to compare the emission tests results in our study against four air quality standards so as to properly analyze the significance of the results. The four standards chosen were the European Union directive on ambient air quality, the National Ambient Air Quality Standards (NAAQS) established by the United States Environmental Protection Agency, the World Health Organization air quality guidelines for gaseous pollutants and China's Ambient Air Quality Standards (CAAQS). Comparisons were also made against existing occupational exposure guidelines such as the US National Institute for Occupational Safety and Health (NIOSH), the US Occupational Health and Safety Administration's (OSHA) for permissible exposure limits (PEL) and the Standard 1910.1000 table Z-1 'Limits for Air Contaminants'.

METHODS

Experimental Material

Moxa floss of different storage years and ratios of the species *Artemisia argyi* gathered from Tongbai mountain in Henan province were obtained from a moxa floss production factory in Henan, Nanyang, China. Storage year refers to the number of years the dried mugwort leaves were stored before processing into moxa floss. Ratio refers to the weight of the starting material (dried mugwort leaves) to the weight of the finished product (moxa floss) in kilogram after processing, for example the ratio 3:1 means 3 kg of dried mugwort leaves was processed into 1 kg of moxa floss. Three moxa floss samples were selected in this study, specifically 3 year and 3:1 ratio (sample A), 10 year and 3:1 ratio (sample B) and 3 year and 15:1 ratio (sample C).

Sampling Procedure of CO, CO$_2$, NO$_2$ and SO$_2$

Sampling was carried out in three empty simulation clinics located on the third floor in a building of Beijing University of Chinese Medicine in 2013. One simulation clinic was used as the sampling site for each moxa floss sample. For each simulation clinic, the walls were painted with emulsion paint, had cement flooring and there was no recent history of renovation. The doors and windows were usually kept closed. The floor area and volume of each simulation clinic was approximately 14.8 m^2 and 50.32 m^3. The university was erected in 1956 and is located in a densely populated residential area on a side road about 10 m away from a busy road. No specific industrial sources for emissions are known of in this area. During the measurements, information on temperature, relative humidity and atmospheric pressure was recorded.

Before each emission test, the doors and windows of the simulation clinic were tightly sealed by a researcher. Sampling was divided into three phases: 1. Pre-combustion phase: the background concentrations of the target gaseous pollutants in the clinic were determined for 1 h prior to each moxa floss sample combustion. 2. Combustion phase: 4 g of moxa floss sample was ignited and each sample took approximately 20 to 25 minutes to burn out to reflect a typical duration of moxibustion administration in a normal treatment setting. 3. Post-combustion phase: the concentrations of the target gaseous pollutants were monitored in the clinic for another hour. Moxa floss samples were burned on a stainless steel tray located in the middle of the room at a height of approximately 1 m, similar to the sampling devices in all three simulation clinics. Each experiment was repeated thrice to obtain an average. The actual average concentrations of the target gaseous pollutants emitted from moxa floss combustion were found by deduction of the background concentrations of the respective gaseous pollutant. The same researcher performed all the aforementioned sampling and emission tests.

A portable non-dispersive infrared CO/CO_2 gas analyzer (HAD-GXH-3010/3011AE, Beijing Heng Odd Instrument Co. Ltd) was used to measure the CO and CO_2 concentrations and sampling points were set at 15-minute intervals for both the pre- and post-combustion phases to monitor the variations in CO and CO_2 concentrations. Gaseous specific chemiadsorption as NO_2^-, SO_4^{2-}, and SO_3^{2-} on a triethanolamine (TEA) coated microporous polyethylene tube (5.8 mm diameter, 60 mm height) allowed for NO_2 and SO_2 sampling using an air sampler (QT-2A, Beijing Pu Sheng Yang Trade Co. Ltd.) at a rate of 0.5 L min^{-1}. The sampling devices were located in the center of the clinic at a height of 1.2 m. The minimum detectable value using this method for SO_2 was 0.007 mg m^{-3}. The detection methods for the gaseous pollutants were based on the Chinese national ambient air quality standard.

RESULTS AND DISCUSSION

CO Concentration

The background concentration of CO in simulation clinics B and C was relatively stable, but there was obvious fluctuation in the background CO concentration in clinic A during pre-combustion monitoring (Fig. 1(a)). The fluctuation observed might have been due to possible photocatalytic surface reactions of wall paint constituents on exposure to light leading to degradations or secondary emissions (Salthammer and Fuhrmann, 2007). The concentration of CO in simulation clinics A, B and C varied from 0.2 ppm to 2.2 ppm, with an average of 0.96 ppm (0.95 mg m^{-3}), 0.9 ppm (0.85 mg m^{-3}) and 1.23 ppm (1.14 mg m^{-3}) in the three clinics, respectively. The maximum post-combustion CO concentration for moxa floss samples A, B and C was 10.1 ppm, 10.6 ppm and 11 ppm, respectively, averaged 9.333 ppm (8.7 mg m^{-3}), which was lower than the hourly limit of 10 mg m^{-3} set by CAAQS. Both the pre- and post-combustion concentrations of CO were below the CO hourly limit set by NAAQS (35 ppm) (40 CFR Part 50) and the WHO (26 ppm) (Raub and World Health Organization, 1999). Both results were also less than the occupational limit recommended by NIOSH (35 ppm) and OSHA (50 ppm) (National Institute for Occupational Safety and Health

(NIOSH), 2012), as shown in Table 1. The post-combustion variation pattern for CO exhibited an interesting trend for all samples, in which the CO concentration continued to increase for 15 minutes after combustion before it remained in a relatively steady concentration (Fig. 1(b)), implying that there was still smouldering after combustion.

The actual CO concentration produced from each type of moxa floss combustion was calculated after deduction from its background concentration. The actual CO concentration emitted was on average 8.18 ppm (7.78 mg m^{-3}), 8.10 ppm (7.65 mg m^{-3}) and 8.68 ppm (7.74 mg m^{-3}) for samples A, B and C respectively. There was no observed difference in the actual average CO concentration produced from the three types of moxa floss. Furthermore, the average emission rate was 0.13 mg min^{-1} per cubic meter, which was lower than the level of 0.16 g min^{-1} recommended by the WHO for household fuel combustion under unvented conditions (World Health Organization, 2014).

CO_2 Concentration

The variation pattern of CO_2 concentration during pre-combustion phase was different from that of CO due to CO_2 expired by the researcher performing the sampling and emission tests (Fig. 2(a)). The average background concentration of CO_2 in each simulation clinic was 0.0756%, 0.0759% and 0.0715%, respectively.

The variation pattern of CO_2 for both pre- and post-combustion phases in each simulation clinic was fairly synchronous (Fig. 2(b)). The CO_2 concentration produced by sample A during post-combustion varied from 0.118% to 0.164%, averaged 0.139%, while the CO_2 concentration of sample B, which was of the same ratio but longer storage year, ranged from 0.107% to 0.168%, averaged 0.136%. When comparing sample A and sample C, which were of the same storage year but different ratio, the CO_2 concentration for the latter ranged from 0.106% to 0.176%, averaged 0.140%. The post-combustion concentration of CO_2 for all the samples were lower than the TWA recommended by NIOSH and OSHA (Table 1).

To calculate the actual CO_2 concentration produced by combustion of moxa floss, the following Eqs. (1) to (4) were used to deduct the background concentration and contribution from human respiration.

$$C_{exp} = C_{b60} - C_{b0} \qquad (1)$$

where C_{exp} is the CO_2 expiratory concentration of the researcher (%), C_{b60} is the background concentration of CO_2 at the 60-minute sampling point (%) and C_{b0} is the background concentration at the 0-minute sampling point (%) during the 1 h pre-combustion phase.

$$C_{exp22.5} = (C_{exp}/60) \times 22.5 \qquad (2)$$

where $C_{exp22.5}$ is the expiratory concentration of the researcher during the combustion phase. An average combustion time of 22.5 minutes was selected because the combustion time took 20 to 25 minutes for all the moxa floss samples to burn out.

Table 1. Comparison of average concentrations of gaseous pollutants released from burning 4 g of moxa floss with international standards and occupational exposure limits.

Gaseous pollutants (hourly)	EU	US	WHO	China	Moxibustion simulation clinic	NIOSH	OSHA	WHO (selected indoor pollutants)
CO	-	35 ppm	26 ppm	10 mg m^{-3}	9.333 ppm	35 ppm (TWA)[a]	50 ppm (TWA)	35 mg m^{-3}
CO_2	-	-	-	-	0.139%	5000 ppm (TWA)	5000 ppm (TWA)	-
SO_2	350 µg m^{-3}	75 ppb	-	150 µg m^{-3}	<7 µg/m^3 (undetectable)	5 mg m^{-3} (TWA)	13 mg m^{-3} (TWA)	-
NO_2	200 µg m^{-3}	100 ppb	200 µg m^{-3}	200 µg m^{-3}	10.556 µg/m^3	1.8 mg m^{-3} (ST)[b]	9 mg m^{-3} (C)[c]	200 µg m^{-3}

[a] TWA: indicates a time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek.
[b] ST: A short-term exposure limit designated by "ST" preceding the value.
[c] C: A ceiling recommended exposure limit designated by "C" preceding the value; unless noted otherwise, the ceiling value should not be exceeded at any time.
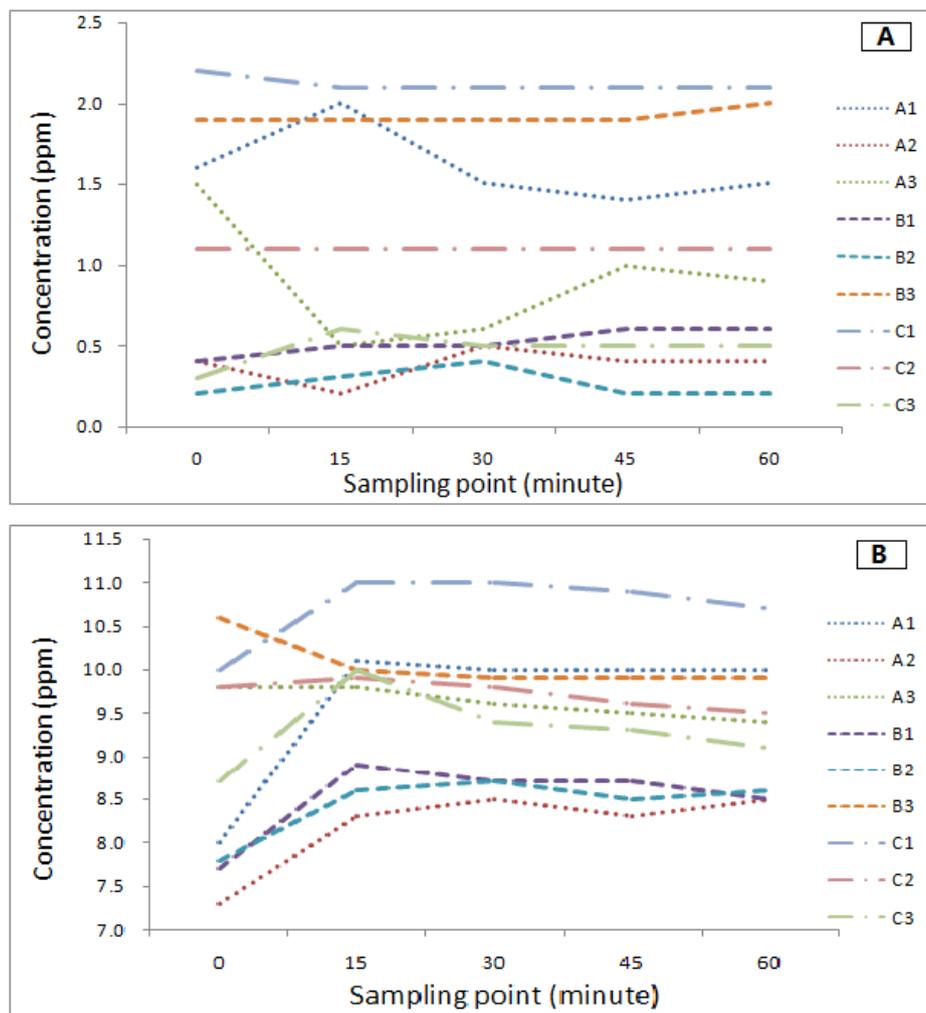
Fig. 1. Variation patterns of CO for (A) background concentration during pre-combustion phase. A: simulation clinic A; B: simulation clinic B; C: simulation clinic C; (B) emission concentration during post-combustion phase. A: sample A; B: sample B; C: sample C.

$$C_{emi+exp} = C_0 - C_{b60} \qquad (3)$$

where $C_{emi+exp}$ is the emission and expiratory concentration of CO_2 (%) during the combustion phase, C_0 is the concentration of CO_2 (%) at the 0-minute post-combustion sampling point.

$$C_a = C_{emi+exp} - C_{exp22.5} \qquad (4)$$

where C_a is the actual CO_2 concentration produced from moxa floss combustion (%).

The actual CO_2 concentration was on average 0.03%, 0.028% and 0.031% for samples A, B and C, respectively. Similar to the results for CO emission, no significant difference could be found in the actual CO_2 concentration produced from the burning of the three moxa floss samples.

SO₂ and NO₂ Concentrations

Concentrations of SO_2 for both pre- and post-combustion phases in the simulation clinics were below detectable limit. For NO_2, the average background concentration in the three simulation clinics was 0.04 mg m⁻³, 0.02 mg m⁻³ and

0.01 mg m⁻³, respectively. The maximum NO_2 concentration during post-combustion was 0.018 mg m⁻³, 0.009 mg m⁻³ and 0.008 mg m⁻³ for the three moxa floss samples, respectively. NO_2 concentrations for both pre- and post-combustion phases were lower than the level of 0.2 mg m⁻³ stated in the ambient air quality standards of Europe, United States, China and WHO (40 CFR Part 50; European Commission; World Health Organization, 2010), and also the short term (ST) limit set by the NIOSH and the ceiling value (C) established by OSHA (National Institute for Occupational Safety and Health (NIOSH), 2012) (Table 1).

NO_2 is a highly toxic oxidizing gas generally produced as a byproduct of combustion processes (Shu *et al.*, 2010). It was thus worth noting that the NO_2 concentration decreased during post-combustion as compared to pre-combustion (Fig. 3). Besides producing thermal stimulation during moxibustion, moxa floss also emits visible light and infrared radiation during combustion that may play a role in the therapeutic actions of moxibustion (Deng and Shen, 2013). It is therefore hypothesized that the decrease in NO_2 may be due to photolysis of a portion of NO_2 in the
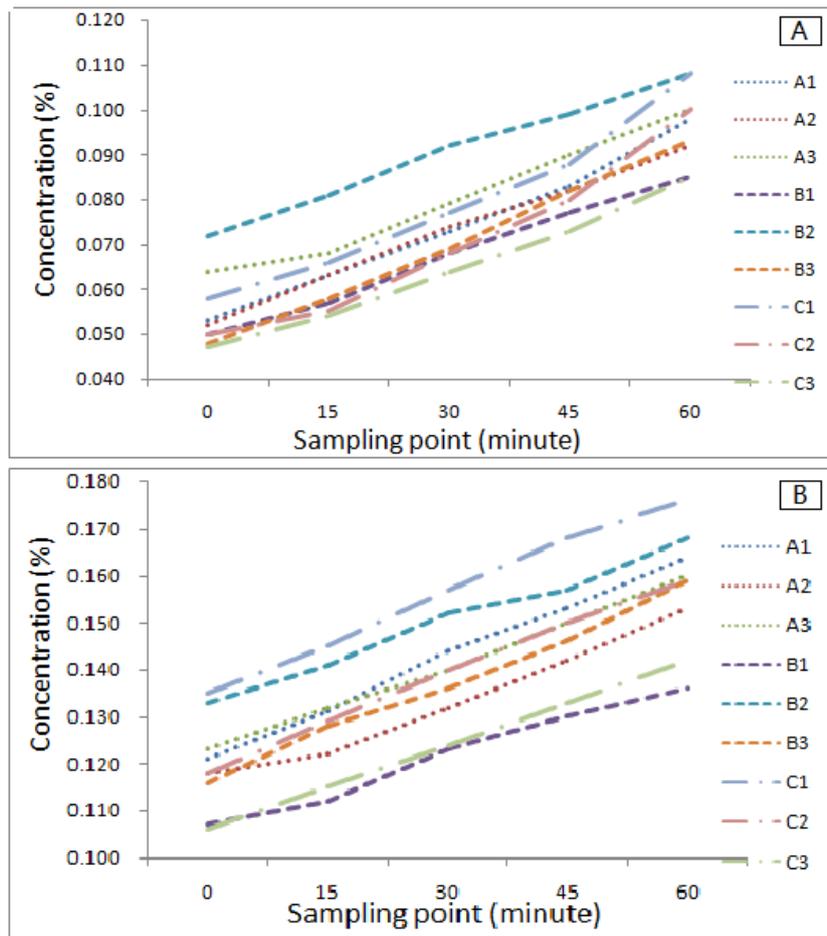
Fig. 2. Variation patterns of CO_2 for (A) background concentration during pre-combustion phase. A: simulation clinic A; B: simulation clinic B; C: simulation clinic C; (B) emission concentration during post-combustion phase. A: sample A; B: sample B; C: sample C.
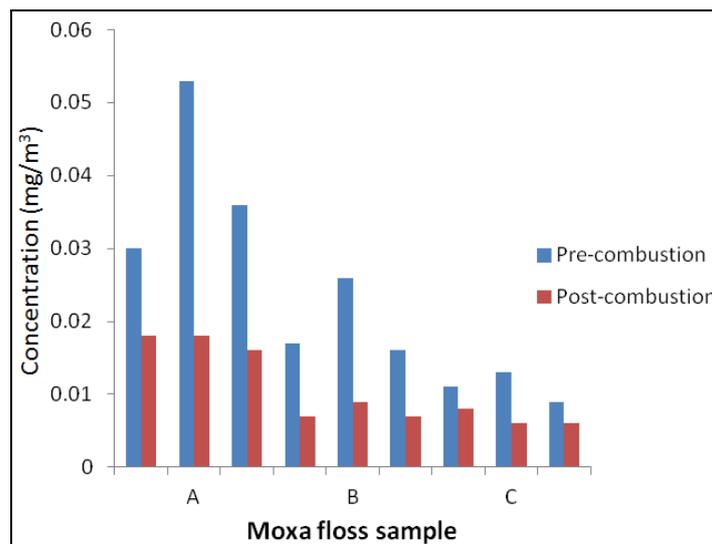

Fig. 3. NO_2 concentration during pre-combustion and post-combustion phases. A: sample A; B: sample B; C: sample C.

simulation clinics to produce NO and other oxidized nitrogen species (NO_z). Furthermore, atmospheric NO_2 could undergo chemical transformations to NO_z, which may also co-vary with NO_2, especially during air stagnation events (Brook *et al.*, 2007). In our study, the windows and doors were sealed throughout the emission tests, which

could highly lead to air stagnation. Moxibustion room has also been found to contain polycyclic aromatic hydrocarbons (PAHs) (Mo *et al.*, 2014). These PAHs could adsorb to air particles and be nitrated by ppm levels of NO_2 containing traces of nitric acid (Pitts *et al.*, 1978). It might also therefore be possible that the combustion of moxa floss led to thermal activation of adsorbed PAHs, resulting in reaction with NO_2 to form nitro-PAHs (NPAHs) (Pitts *et al.*, 1978; Pitts, 1979; Kristovich and Dutta, 2005).

CONCLUSIONS

To the best of the authors' knowledge, this is the first report that systematically studied the gaseous pollutants in environmental moxa smoke during the combustion of moxa floss samples of different storage years and ratios. The concentrations of CO, CO_2, SO_2 and NO_2 from burning 4 g of moxa floss did not exceed the hourly limit stated in available international standards for ambient air quality and were far lower than the occupational exposure limits set by NIOSH and OSHA.

In summary, the levels of target gaseous pollutants from 4 g of moxa floss combustion were not produced in quantities to cause concerns about exceeding present international standards and occupational exposure limits. However, practitioners and patients have different levels of exposure to moxa smoke. It is thus important to recognize and control occupational and non-occupational exposure to gaseous pollutants. To reduce exposure, possible measures such as good ventilation in moxibustion clinics should be undertaken. Data from our present study is an important source of information when assessing air quality in moxibustion clinics by professional authorities. Future studies could be conducted in an indoor mass balance model (box model) or test chamber to remove the influence of air exchange such as air change rate (ACH) and other possible factors on the emission of the gaseous pollutants.

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CONFLICT OF INTERESTS

None declared.

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